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Disjunctive eye movements in strabismics

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Abstract

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DISJUNCTIVE EYE MOVEMENTS

IN STRABISMICS

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INTRODUCTION

A survey of past and current literature indicates, that much research has been undertaken to determine the convergence/ divergence movement patterns of normal (non-strabismic) eyes, (Alpern and Wolter, 1956; Zuber and Stark, 1968). It has been shown that the vergence system responds to many stimulus cues, such as accommodative and proximal stimuli and retinal image disparity. In fact, a study by Rashbash and Westheimer, (1961), verified that normal convergence responds to direction, magnitude, velocity and acceleration of disparity. Certain vergence characteristics have thus been quantified. It is now known that in response to abrupt, unpredictable changes in the velocity and direction of target vergence; eye-vergence movements have a latency of between 160 and 200 milliseconds, accelerate at a velocity directly proportional to the stimulus amplitude and acheive a constant velocity, which is a function of the amplitude of the disparity, (the constant of proportionality for small amounts of disparity being, 10 degrees/ second/degree of disparity). When changing stimulus vergence can be anticipated, as with sinusoidal waveform targets, the response latency approaches zero and the amplitude and velocity of response almost exactly matches that of the stimulus.

It is assumed that abnormal binocular vision interferes with oculomotor responses and limits the use of potential cues to vergence change; cues that are easily detected and incorporated by normal eyes. However, some vergence mechanisms appear to function in strabismics. Tropic individuals have been known to respond to accommodative and proximal stimuli. In studies similar to this research, Schossler has recently demonstrated responses to step (square wave) stimuli by squinters with normal and anomalous retinal correspondence. Characteristic of strabismics, are responses that are highly variable and much greater response latencies than found in normals.

Amblyopes appear to exhibit an asymmetrical zone of reduced position sensitivity about the fovea of the amblyopic eye, (Irvine, 1948). It seems to extend more onto the nasal than the temporal half of the retina. Amblyopic eyes show unsteady fixation and poor eye movements, when tested with eye track recording equipment, (von Noorden, 1966 and 1970). Oculomotor responses by amblyopes to sudden changes of position or pendular motion, are unsteady and irregular, (von Noorden and Mackensen, 1962; von Noorden and Burien, 1958). Tracking by similar subjects, presents a picture of inaccurate prediction and consequent overshooting and undershooting, (von Noorden, 1966). These tracking movements are particularly abnormal when responding to targets imaged on the nasal hemi-retina, (Schor, 1971). Similar difficulty is encountered by the pursuit system, in response to nasalward motion of the retinal image, (Schor, 1975).

Individuals with abnormal retinal correspondence (ARC) respond very slowly and inaccurately to step changes in convergence stimuli, (i.e. base out prism), (Alpern and Hoffstetter, 1948; Bagolini, 1974). This is an indication that the binasal scotomata may interfere with vergence response to disparate stimuli.

Some researchers hypothesize that abnormal motor responses may result from:

i) reduced monocular position and velocity sensitivity or,

ii) abnormal binocular cortical integration or,

iii) a motor anomaly.

Our research is designed to:

i) examine the amplitude, velocity, latency and stability of disjunctive eye movements, by patients exhibiting strabismus and associated amblyopia or anomalous retinal correspondence, to fast (square wave) and slow (sinusoidal wave) stimuli,

ii) distinguish between monocular and binocular sensory interference of disjunctive eye movement and

iii) examine the possible involvement of a motor anomaly in the convergence/divergence response of subjects with amblyopia and/or anomalous retinal correspondence.

SUBJECTS

The experimental subjects were seven students at Pacific University, College of Optometry and one patient of the Pacific University Clinic. All were strabismic, exhibiting tropias of 2 or more. Only subject M.N. had received any formal visual training prior to this research. (The eye track recording sessions subsequently served as part of her training program). A member of the optometry college staff served as control subject.

Candidates had been routinely examined in the Pacific University Clinic and classified as strabismic. Further testing for eccentric fixation, subjective angle, objective angle, angle of anomaly was done with Haidenger Brush, Maxwellian Spot, Belchowski After Image Test, and troposcope. Correspondence was considered anomalous if an angle of anomaly greater than 2 was consistently manifested. For convenience, in several cases, the poorer seeing eye, although not 20/40 or poorer, is referred to as the amblyopic eye.

Complete subject data is summerized in Table I.

TABLE I

SUBJECT DATA

SUBJECT	EYE	REFRACTIVE CORRECTION	SNELLEN V.A.	EF	∠S()	∠O()	∠A()	CORRESPONDENCE	NON-DOMINANT EYE
B.E.**	OD.	plano	20/15	no	2-3BI	2-3BI	0	normal	O.S.
	OS.	plano	20/30	no					
B.K.	OD.	-7.00-2.50x180	20/20	no	12-14 BO	16-18 BO	4 BO	anomalous	O.S.
	OS.	-6.00-2.50x180	20/15	no					
E.B.	OD.	+1.75-0.50x 60	20/15	no	2BO	2BO	0	normal	O.D.
	OS.	+1.25-0.25x101	20/15	no					
M.K.	OD.	+2.00-0.50x180	20/15	no	22-23 BO	22-23 BO	0	normal	O.S.
	OS.	+2.50-1.00x180	20/15	no					
M.N.**	OD.	plano	20/20	no	3-5BI	3-5BI	0	normal	O.S.
	OS.	plano	20/40	no					
M.O.	OD.	plano-0.75x155	20/20	no	varia-ble	3-4BO	varia-ble	anomalous	O.S.
	OS.	-0.25-0.75x 30	20/25	yes					
M.S.**	OD.	plano	20/20	no	8-10BO	8-10BO	0	normal	O.S.
	OS.	plano	20/20	no					
P.S.	OD.	-1.00-1.00x 95	20/25	no	1BO	3BO	2BO	anomalous	O.D.
	OS.	-0.50-1.50x 85	20/15	no					
C.S.*	OD.	-1.75-0.75x180	20/15	no	—	—	—	normal	O.S.
	OS.	-1.75-0.75x180	20/15	no					

*----denotes control subject

**---plano refractive correction indicates that no corrective lenses were used in experimental trials

METHODS

APPARATUS

The apparatus consists of infrared photocell receptors, mounted in a trial frame, and connected to a Biotronics SGVH/2 Eye Movement Monitor. This instrument, in turn, relays signals to a Honeywell 1508B Visicorder, which records four traces;

trace 1: monitors right eye movement

trace 2: monitors left eye movement

trace 3: summates right and left eye movements

trace 4: records the stimulus

Stimulus presentation is by a pair of Tektronics oscilloscopes, set up in a mirror haploscope design. Each oscilloscope is 1.5 meters from its respective mirror plane and presents line stimuli to only one eye. An F33 Function Generator linked to the oscilloscopes, varies the amplitude and frequency of the target stimuli. A permanent forehead/chin rest is mounted 0.2 meters from the mirrors.

The total apparatus is detailed in Diagram I.

PROCEDURE

The experimental procedure is carried out under dark illumination and is as follows. The subject, wearing the trial frame incorporating correcting lenses for his ametropia, is placed firmly in the forehead/chin rest. The photocell receptors are adjusted to maximum monitoring distance. A stationary, vertical line of 6 arc length is presented on each oscilloscope screen and the mirrors are adjusted so that the lines appear superimposed to the subject. D.C. bias for each eye is zeroed on the monitor.

The stimulus amplitude is set to 4° of version movement at a frequency of 0.5 Hz., and the gain of the right and left eyes are matched to produce a summation of zero on trace 3.

The testing sequence then proceeds in fourteen steps. Steps I to 6 represent symmetrical version movement stimulation. Line stumuli are presented at 0.5 Hz. and move 4 side to-side, across each oscilloscope screen. Stimulus conditions are:

1. binocular square wave- stimulus to both eyes
2. binocular sinusoidal wave- stimulus to both eyes
3. monocular square wave (OD)- stimulus to right eye, left eye oscilloscope blacked out
4. monocular sine wave (OD)- stimulus to right eye, left eye oscilloscope blacked out
5. monocular square wave (OS)- stimulus to left eye, right eye oscilloscope blacked out
6. monocular sine wave (OS)- stimulus to left eye, right eye oscilloscope blacked out

Steps 7 and 8 elicit symmetrical vergence response. The stimulus moves a total of 4° at 0.2 to 0.25 Hz.,(2° movement on each oscilloscope screen).

7. binocular square wave- stimulus to both eyes
8. binocular sine wave- stimulus to both eyes

Asymmetrical vergence stimuli are presented in steps 9 through 12. One eye views 4° movement at 0.2 to 0.25 Hz., while the opposite eye's target is a stationary line.

9. asymmetric square wave (OD)- moving stimulus to right eye, stationary line to left eye
10. asymmetric sine wave (OD)- moving stimulus to right eye, stationary line to left eye
11. asymmetric square wave(OS)- moving stimulus to left eye, stationary line to right eye
12. asymmetric sine wave (OS)- moving stimulus to left eye, stationary line to right line

Finally, accommodative convergence response will be monitored by introduction and removal of a minus power lens before one eye, while it views a stationary line. The other eye will remain unstimulated (blacked out screen), in order to measure any reciprocal response. The lens introduced will be selected according to individual AC/A's, so as to produce approximately 4° of eye movement in each subject. Frequency will be such that the subject can comfortably clear the target.

13. accommodative convergence (OD)- stimulus and lens to right eye, left eye oscilloscope blacked out
14. accommodative convergence (OS)- stimulus and lens to left eye, rifht eye oscilloscope blacked out

Subject responses are evaluated with regard to amplitude, velocity, latency, and stability in subsequent tables.

APPARATUS

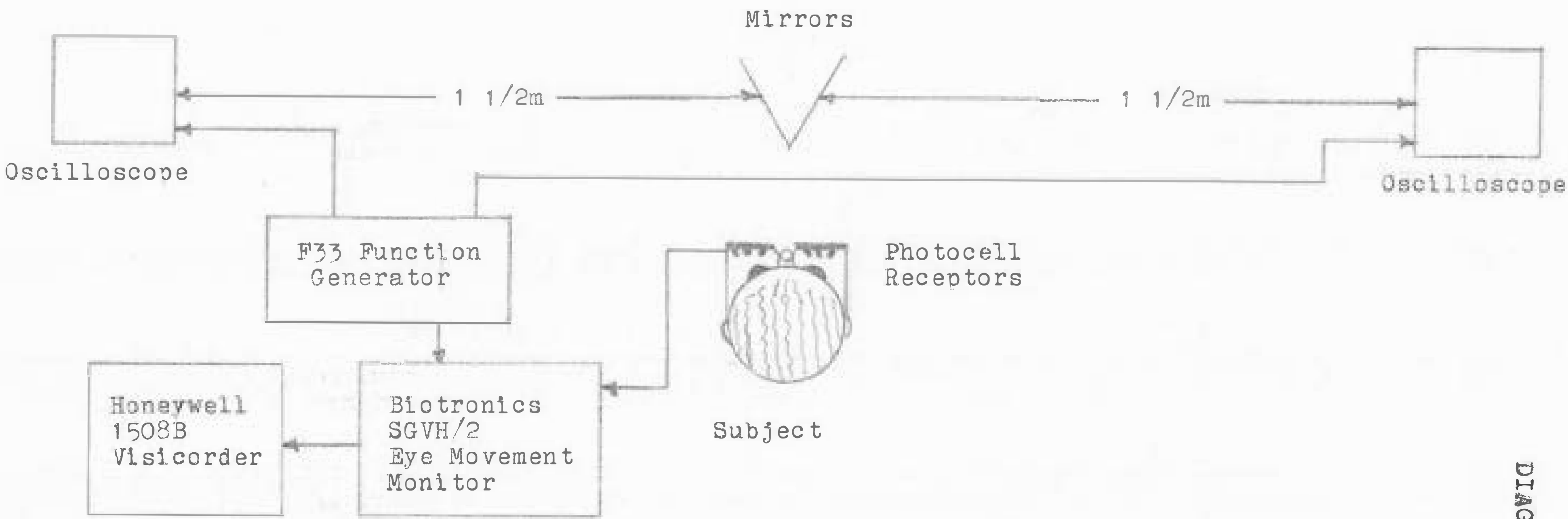

DIAGRAM I

I. VERSION

SUB	AMP (divs/4^{o})	(1) Binocular Square Latency Right, (msec)	Left	No. of Saccades Right,	Left	Amplitude (divs/4^{o})	(2) Binocular Sine Cog Wheel Saccades Right,	Left
OD								
CS	7.0	-65	-45	1	1	7.0	0	0
BE	6.0	-105	-100	0	0	9.0	0	0
BK	9.5	-115	-215	2	1	10.0	1	0
EB	13.0	- 10	- 55	1	1	12.0	0	1
MK	13.0	- 80	- 80	0	0	12.0	1	1
MN	7.5	+ 15	- 50	1	0	9.0	1	0
MO	9.5	-100	-145	0	0	8.0	1	0
MS	5.0	+100	-100	0	0	5.0	0	0
PS	12.5	- 65	- 50	1	0	11.5	0	0
OS								
CS	9.5	- 65	- 45	1	1	9.5	0	0
BE	6.0	-105	-100	0	0	10.0	0	0
BK	9.5	-115	-215	1	2	9.5	0	1
EB	13.0	- 10	- 55	1	1	12.0	0	1
MK	13.0	- 80	- 80	0	0	12.0	1	1
MN	7.5	+ 15	- 50	1	0	9.0	1	0
MO	9.5	-100	-145	0	0	8.0	1	0
MS	5.0	+100	-100	0	0	5.0	0	0
PS	12.5	- 65	- 50	1	0	11.5	0	0

SUB	AMP (divs/4^{o})	(3) Monoc. Square (Right Eye) Latency (msec) Left	Right	No. of Saccades Left	Right	AMP (divs/4^{o})	(4) Monoc. Sine (Right Eye) Cog Wheel Saccades Left	Right
CS	7.5	0	- 65	1	1	7.5	0	0
BE	6.0	- 90	- 45	0	0	8.0	0	0
BK	8.5	-125	- 90	1	1	10.0	0	1
EB	12.0	- 50	- 50	1	2	11.0	0	0
MK	14.0	-135	-140	0	0	13.0	2	1
MN	7.0	- 85	- 95	1	0	7.5	0	0
MO	7.0	-150	- 75	0	0	6.0	0	0
MS	4.0	-160	- 40	0	0	4.0	0	0
PS	12.5	-130	- 20	0	0	14.5	0	1

SUB	AMP divs/4°	(5) Monoc Square (left eye) Latency (msec) Right	Left	No. of Saccades Right	Left	AMP divs/4°	(6) Monoc. Sine (left eye) Cog Wheel Saccades Right	Left
CS	10.0	- 60	-105	0	1	10.0	1	0
BE	5.5	-200	-195	1	0	7.0	1	0
BK	10.0	+ 31	-138	1	1	10.0	1	1
EB	11.0	+170	-110	1	0	10.5	0	0
MK	11.0	- 90	- 80	0	0	10.0	1	0
MN	13.0	-220	- 20	1	1	14.5	1	0
MO	11.0	-160	-120	0	1	9.0	1	1
MS	4.0	+ 5	+100	1	0	5.0	0	0
PS	13.0	-153	-179	0	0	14.5	0	0

II. VERGENCE

SUBJ.	(7) Sym Square AMP con-div (°)	Vel con-div (°/sec)	Latency con-div (millisec)	Oscillations rate - con-div (Hz)	amp con-div (°)	(8) Sym Sine AMP con-div (°)	Delay con-div (millisec)	Oscillations rate - con-div (Hz)	AMP con-div (°)	Period	Phase Lag (Deg.)
CONVERGE											
CS	4.9	11.4	- 80	1.5	0.85	4.4	- 67	2.7	0.97	1/4	9.0
BE	4.4	7.6	-310	2.1	0.73	2.7	-1000	4.0	0.67	1/4	90.0
BK	5.5	8.8	-279	1.5	1.50	5.9	- 250	1.5	1.50	1/6	50.0
EB	6.3	11.3	-283	2.5	0.62	3.7	- 150	2.3	0.62	1/5	20.0
MK	5.8	7.7	-333	0.0	0.00	3.9	- 300	2.5	0.46	1/4	20.0
MN	4.0	6.5	-117	3.4	1.60	5.5	- 200	4.0	1.30	1/4	18.0
MO	6.4	10.4	-283	2.5	0.67	7.7	- 353	3.3	0.44	1/3	36.0
MS	7.4	13.6	-600	1.5	1.90	6.2	- 100	1.3	1.40	1/4	11.0
PS	4.1	4.8	-561	3.0	0.70	5.8	-2000	3.6	1.20	1/8	90.0
DIVERGE											
CS	4.4	14.3	-125	2.9	0.97	3.8	- 167	2.1	1.40	Same as above	Same as above
BE	4.0	5.0	-350	0.0	0.00	2.2	-1300	2.1	0.53		
BK	3.7	8.0	-386	0.0	0.00	6.0	- 350	2.0	0.84		
EB	6.5	11.0	-367	0.0	0.00	4.4	- 283	2.2	0.77		
MK	5.6	4.6	-325	3.3	0.38	4.0	- 275	2.7	0.46		
MN	4.4	6.6	- 50	2.5	1.00	4.9	- 211	0.0	0.00		
MO	7.2	7.8	-167	2.0	0.44	8.2	- 263	4.0	0.44		
MS	5.4	6.4	+400	1.5	1.90	7.0	- 150	1.3	1.40		
PS	2.8	5.6	-393	3.2	0.80	6.8	-1600	6.1	0.70		

SUBJ.	(9) Asym Square (right eye) AMP con-div (deg)	Vel con-div (deg/sec)	Latency con-div (msec)	Oscillations rate con-div (Hz)	Oscillations amp con-div (deg)	(10) Asym Sine (right eye) AMP con-div (deg)	Delay con-div (msec)	Oscillations rate con-div (Hz)	Oscillations amp con-div (deg)
CONVERGE									
CS	5.7	9.6	-206	0	0	4.3	-183	0	0
BE	2.1	5.0	-280	2.2	0.48	1.2	-333	1.0	0.6
BK	2.9	4.0	-363	0	0	5.1	-1150	1.0	1.3
EB	3.4	13.0	-200	2.5	0.3	4.4	0	2.5	0.6
MK	6.0	6.1	-163	2.5	0.3	3.9	-67	3.3	0.3
MN	6.6	8.8	-240	4.0	1.3	7.3	-278	6.7	0.53
MO	4.8	9.6	+58	2.5	0.9	4.9	-90	0	0
MS	5.4	7.0	-263	1.0	1.6	8.2	0	0.25	1.6
PS	5.6	8.6	-1000	3.7	1.5	6.5	-283	3.8	0.5
DIVERGE									
CS	4.3	15.4	-206	3.1	1.1	4.0	-167	0	0
BE	1.7	5.0	-143	1.9	0.6	1.9	-560	1.0	0.6
BK	3.5	4.4	-436	0	0	5.7	-775	1.0	1.3
EB	3.4	3.0	-220	2.5	0.3	4.2	0	2.5	0.3
MK	5.5	5.8	-179	3.5	0.46	3.9	-75	3.3	0.3
MN	6.1	10.1	-175	0	0	8.0	-238	0	0
MO	4.4	7.2	-40	0	0	6.2	-200	3.0	0.44
MS	4.6	7.0	-425	0.7	2.4	8.2	0	1.0	1.6
PS	6.2	6.7	-756	2.6	1.7	6.3	-400	2.9	0.7

SUBJ.	(11) Asym Square (left eye) AMP con-div (deg)	Vel con-div (deg/sec)	Latency con-div (msec)	Oscillations rate con-div (Hz)	Oscillations amp con-div (deg)	(12) Asym Sine (left eye) AMP con-div (deg)	Delay con-div (msec)	Oscillations rate con-div (Hz)	Oscillations amp con-div (deg)
CONVERGE									
CS	4.0	7.3	-139	4.3	0.8	3.7	+31	4.0	0.48
BE	4.0	7.7	-36	1.6	0.6	2.6	+21	1.5	0.85
BK	8.3	6.7	-542	1.5	2.1		NO DATA		
EB	3.6	8.0	-340	2.0	0.3	3.1	-100	3.3	0.4
MK	5.0	7.0	-240	5.0	0.3	5.0	-333	5.0	0.3
MN	16.4	17.8	-117	3.3	0.53	11.0	-122	3.7	1.0
MO	4.7	8.4	-200	2.5	0.9	5.9	-57	2.5	0.66
MS	11.2	23.2	-400	1.7	2.0	8.8	+167	1.0	1.8
PS	3.0	10.6	-200	6.3	0.5	5.7	0	3.1	0.8
DIVERGE									
CS	3.5	7.3	-144	3.3	0.8	3.6	+113	4.3	0.48
BE	3.4	6.1	-217	1.2	0.6	3.0	-200	1.6	1.2
BK	8.3	8.2	-708	1.6	1.7		NO DATA		
EB	3.5	5.5	-240	2.9	0.46	2.3	-50	0	0
MK	5.2	5.2	-240	2.5	0.6	5.2	-350	2.0	0.6
MN	14.4	12.7	+375	0	0	11.0	-300	6.7	0.53
MO	5.3	8.9	-310	3.7	0.44	5.7	-243	3.3	0.44
MS	9.8	8.0	-467	1.7	2.0	6.6	-800	1.0	1.8
PS	3.2	10.7	-300	2.9	0.7	4.3	0	3.3	0.9

SUBJ.	(13) AMP con-div (deg)	Accom. Conv. (left eye) Vel con-div (deg/sec)	Latency con-div (msec)	Oscillations rate con-div (Hz)	- amp con-div (deg)
CONVERGE					
CS	6.8	10.0	-200	2.5	0.8
BE	10.7	17.3	-90	0	0
BK	8.8	4.5	-250	1.2	1.5
EB	5.4	10.8	-280	0	0
MK	7.0	14.0	-250	0	0
MN	10.3	26.4	-200	3.0	1.1
MO	7.1	8.1	-325	2.9	0.66
MS	13.6	14.0	-150	1.6	1.6
PS	2.9	4.8	-717	2.4	2.0
DIVERGE					
CS	6.3	8.8	-94	2.5	1.2
BE	10.4	15.3	+30	0	0
BK	4.4	4.5	-1000	1.33	0.63
EB	6.2	8.8	-238	2.5	0.3
MK	7.8	4.3	-275	2.5	0.6
MN	8.4	14.4	-142	3.0	0.8
MO	7.7	8.9	-200	2.5	0.66
MS	16.0	8.0	-250	1.7	1.6
PS	3.5	6.7	-870	2.5	1.1

SUBJ.	(14) AMP con-div (deg)	Accom. Conv. (right eye) Vel con-div (deg/sec)	Latency con-div (msec)	Oscillations rate con-div (Hz)	amp con-div (deg)
CONVERGE					
CS	8.9	9.1	-91	3.3	2.7
BE	10.0	18.9	-217	1.4	1.5
BK	2.3	2.1	-675	2.5	0.42
EB	6.6	18.5	-240	0	0
MK	10.5	15.4	-250	0	0
MN	19.2	63.0	-217	4.4	2.1
MO	10.6	21.3	-321	2.5	0.88
MS	12.0	9.4	-300	1.4	0.8
PS	3.6	7.0	-638	4.2	0.9
DIVERGE					
CS	8.1	15.0	-105	2.3	1.4
BE	10.5	17.2	-50	2.3	1.3
BK	3.1	2.3	-788	2.5	0.42
EB	7.3	11.7	-230	0	0
MK	10.0	5.2	-200	2.9	0.77
MN	9.6	27.0	-233	3.2	5.9
MO	10.5	12.4	-179	0	0
MS	12.0	10.0	-50	1.4	1.2
PS	4.2	7.0	-433	2.9	1.7

RESULTS

SUBJECT: C.S.

C.S. was the control subject and his eye movement patterns were compared to the literature norms, to be used as a baseline for the experimental subjects in our research.

Versions: Mean amplitude was 8.25 divisions/4° and approximately equal for both square wave (SQ) and sine wave (SN). SQ latency ranged from 0 to -65 milliseconds for movement to the right and -45 to -105 milliseconds for movement to the left. This was less than normal latency, which is considered to be -160 to -200 milliseconds. C.S. exhibited oscillations rarely, but when present, they were equal in number and amplitude in both right and left directions. This correlated with expected norms for nonstrabismics.

Symmetrical Binocular Vergence: SQ and SN convergence/divergence amplitudes (3.8° to 4.9°) compared well with target amplitude. Convergence and divergence SQ velocities were 11.4° and 14.3°/second respectively, which were slower than the expected 40°/second as predicted by a 4° disparity at the constant of proportionality of 10°/second/°disparity. Latency was -100 msecs. and -150 msecs. for SQ stimulated convergence (conv) and divergence (div) and -67 msecs. and -167 msecs. for SN. Conv oscillations were at 1.5 to 2.7 Hz. with an amplitude of 0.85° to 0.97°. Those for div. were at 2.1 to 2.9 Hz. and 0.97° to 1.4°. Normal oscillations range from 2.5 to 3.3 Hz. and have an amplitude of 0.2° (12 arc minutes).

Asymmetric Vergence: Again vergence amplitudes compared closely with stimulus amplitudes. Response velocities were much slower than expected, with right eye div faster than other movements. Latencies were within normal limits when following SQ, but slow during right eye (RE) SN response and slightly predicting during left eye (LE) SN tracking. Normal delay for SN approaches zero. Oscillations were rare and at about 4.0 Hz. and 0.48°. Evidence that Herring's Law applies during asymmetric convergence was demonstrated by an initial version movement preceding vergence.

Accommodative Convergence: Velocities were slow, with the exception being div during LE SQ stimulation, which was also slow, but significantly faster than the other movements. Latencies ranged from -90 to -200 msecs. and oscillations were within the normal extent of 2.5 to 3.3 Hz..

SUBJECT: B.E.

Versions: B.E. showed good versional movement with very few, if any, oscillations. Those oscillations that did occur, were only present in the left eye and only when it moved nasally. Latencies were all less than -200 msecs. and approximately equal for movement to the right and to the left. However, monocular LE stimulation produced a latency at least twice as great as that of monocular RE or binocular stimulation.

Symmetrical Vergence: Response amplitudes matched the stimulus well for SQ, but were only about one-half the target motion for SN. This was consistent with slightly slow SQ latencies (300 to 350 msecs) and a full one second SN latency, producing a SN phase lag of 90°,(normal phase lag= 0°). The difference between SQ and SN responses is further explained by the fact that oscillations were present during both conv and div to SN motion and only during SQ conv. The 5.0°/ second to 7.6°/ second velocity range was very slow; about one-half the baseline set by C.S..

Asymmetric Vergence: B.E. appeared to have more difficulty tracking with RE than LE, which was inconsistent, since the LE was his poorer eye. In both monocular conditions, version movements, rather than vergence, were common and not restricted soley to conv nor div. When the RE was tracking SQ, latency of conv was much greater than div and when LE was tracking, the situation was reversed. During SN response, latency, following monocular RE stimulation was more than twice that following monocular LE stimulation and once again, div lag was larger than conv lag. Velocities of RE and LE responding to SQ and SN were slow.

Accommodative Convergence: RE and LE correlated well with regard to amplitude ($\simeq 10^\circ$) and velocity ($\simeq 17^\circ$/second). When the RE was viewing the stimulus, latencies were significantly less than during LE viewing: -90 and +30 msecs. compared to -217 and -50 msecs.. Oscillations were present only during LE stimulation at 1.4 to 2.3 Hz and were equal for both conv and div.

SUBJECT: B.K.

Versions: B.K. was able to track all version stimuli. Latencies were approximately equal for monocular RE viewing, but the lag to the right was much less than to the left during monocular LE and binocular stimulation. Correspondingly, oscillations were greater to the right than to the left.

Symmetrical Vergence: The period was increased to 6.0 to 9.5 seconds to allow B.K. to track the stimulus with any accuracy. During SQ stimulation, he converged consistently, but did not diverge with every convergence stimulus. Moreover, div responses were frequently preceded by blinks and initiated by a large version to the left. Amplitude of conv response to SQ was greater than div response, but both were close to stimulus amplitude. Latency was shorter for conv. Velocity was slow compared to our normal subject, but consistent with the increased period. SN amplitude was well matched for conv and div, but indicated a tendency to over-vergence. However, div latency was considerably larger than conv. Oscillations during all symmetrical vergence conditions were slow at 1.5 to 2.0 Hz. and not direction dependent.

Asymmetric Vergence: RE responses to SQ were less than LE with regard to amplitude and velocity. Both RE and LE latencies were greater than the normal ~200 msecs. with div lagging more than conv. SN response amplitude was also similar to the stimulus, but latencies were very large, approaching one msec.. This produced a phase lag of 60°. As in binocular vergence, there was a characteristic version movement to the left following div stimulation, in both SQand SN phases. Again, oscillations were random at 1.0 to 1.5 Hz..

__Accommodative Convergence:__ RE stimulation brought about a more pronounced response than LE stimulation. Div amplitude was one half that of con and div latency was four times slower than the opposing lag. In both testing situations, response was very poor with more versional than vergence movement. When vergence did occur, movement was small and lagged by 0.75 to 1.0 second. Oscillations were random at 1.2 to 2.3 Hz..

SUBJECT: E.B.

Versions: E.B. exhibited consistent versions. Latencies were small, but there was a tendency to anticipate the stimulus upon movement to the right, in response to step stimuli. Oscillations were infrequent; however, when present were right direction dependent.

Symmetrical Vergence: SQ responses show a tendency toward over-vergence, a slow velocity and a slightly longer latency than the normal -150 to -200 msecs.. Oscillation rate was 2.5 Hz. and was convergence dependent. SN responses matched the stimulus amplitude and showed a normal latency. Oscillations were within normal limits and random.

Asymmetrical Vergence: In both RE and LE monocular conditions, SQ response amplitude was consistent with the stimulus. When the RE was tracking, conv velocity was much faster than div. Latencies were not predicting as expected, but rather, were on the slow side of normal. Oscillations were random at 2.5 to 3.3 Hz. Oscillation amplitudes were closer to expected norms (0.2° arc) than in any other subject. SN response amplitudes were also consistent with the stimulus with a 0 to -100 msecs. latency. Oscillations were at 2.5 to 3.3 Hz. and random with RE viewing and convergence-dependent with LE viewing.

Accommodative Convergence: Each eye responded equally during its respective monocular stimulation. Velocities were slow, but faster than the control subject, with conv slightly faster than div. Latencies and oscillations were normal.

SUBJECT: M.K.

Versions: Versions were generally consistent and well matched to the right and left. Latencies were less than -150 and equal in either direction. Oscillations were absent during SQ and infrequent during SN. Those that were present were right direction dependent.

Symmetrical Vergence: SQ response amplitudes of 5.6° and 5.8° indicated a tendency toward over-vergence. Velocity was slow with div being significantly slower than conv. Latencies at -333 and -325 msecs. were greater than in normals. Oscillation rate was the expected 3.3 Hz. and divergence-dependent. SN responses showed normal amplitudes (3.7° and 4.4°) with slightly large latencies, (-300 and -275 msecs.). Oscillations were random at 2.5 Hz..

Asymmetric Vergence: Again B.E. tended toward over-vergence with slow velocities, when responding to SQ. Latencies were normal at -163 and -240 msecs.. SN patterns were similar to SQ, except that RE latency was less than in normals and LE latency was larger than in normals. Oscillations for all asymmetric conditions, ranged from 2.5 to 3.3 Hz.. Like the previous subject, M.K. demonstrated oscillation amplitudes close to , but slightly greater than normals. Generally speaking, div oscillations were larger than those of conv.

Accommodative Convergence: M.K. responded well to this stimulus. However, amplitude was much greater with LE stimulation. Conv velocity was greater than div, but both were less than norms. Latency was about -250 msecs. and oscillations at 2.5 to 2.9 Hz., occurred during div only.

SUBJECT: M.N.

<u>Versions</u>: Binocular and monocular RE amplitudes were consistent, but monocular LE amplitude was signifcantly larger than the former two, (almost twice as great). Similarly, binocular and monocular RE latencies were consistent in right and left directions, although those with stimulation to both eyes were much less than with RE stimulus only. When the LE viewed the target monocularly, leftward latency was ten-fold greater than rightward lag. Oscillations occurred in no specific pattern.
<u>Symmetrical Vergence</u>: SQ responses matched stimulus amplitudes. Conv/div velocities were equally slow, while conv latency was twice that of div. Both lags were less than expected norms. Oscillation range was 2.5 to 3.4 Hz., and random. Some over-vergence was evident in SN response amplitudes. Latencies were slightly slow and about equal during both disjunctive move-ments. Oscillations were convergence-dependent at 4.0 Hz..
<u>Asymmetric Vergence</u>: When the moving target was before the RE, M.N. demonstrated a small over-vergence and slow reponse vel-ocities to both SQ and SN patterns. Latencies were large and conv was slower to respond than div. Oscillations occurred only during conv at a frequency of 4.0 to 6.7 Hz., (much faster than frequency norms). Tracking by the amblyopic LE was characterized by huge amplitudes. LE velocity was faster than with RE. Latencies wew highly variable, ranging from +375 to -300 msecs.. Oscillations were rare.

Accommodative Convergence: Once again, responses were very very large for both monocular conditions; conv being greater than div in the two situations. Latencies were normal. When the RE was scanning the target and the LE was making vergence movements, Oscillations were minimal, But, when the situation was reversed, instability was evident in the many random oscillations at 3.2 to 4.4 Hz.. Velocities were greater than with any other subject. In fact, when the LE was viewing the stimulus and the RE moving, velocity reached as high as 64°/second, exceeding the 40°/second norm for nonstrabismics. In both monocular situations, velocity of conv was faster than div.

SUBJECT: M.C.

Versions: Versional SQ and SN stimuli, binocularly and to the RE monocularly, produced fair tracking motion. Latencies were less than -150 msecs., with movement to the left lagging more than rightward gaze. Oscillations were infrequent and when they did occur, were equal in number for both right and left directions. Poor versional movement was evident when the LE alone, viewed the target. Latency to the right was greater than to the left. Oscillations were plentiful, occurring more with leftward response.

Symmetrical Vergence: Over-vergencw was consistent in both SQ and SN responses. Velocities were moderately slow and latencies were slightly large with conv responding marginally later than div, (-283 to -353 msecs. as compared to -167 to -267 msecs.). Oscillations were again frequent and equal for both disjunctive movements, (rate- 2.0 to 4.0 Hz.).

Asymmetric Vergence: SQ tracking coincided with stimulus amplitude, but velocity was slow. RE response tended toward prediction, (lags were +58 and -40 msecs.) while the LE showed a slightly larger then normal latency (-200 to -310 msecs.). SN. motion was erratic in both eyes. Over-vergence was common. Div latencies (-200 to -243 msecs.), were greated then conv lags (-57 to -90 msecs.). Oscillations were random at 2.5 to 3.3 Hz. for both stimulus patterns.

Accommodative Convergence: When the RE viewed the stimulus and the LE made vergence movements, velocity was slow. In the reverse situation, response was much greater in amplitude and much faster. Latencies for both accommodative conv conditions were slightly larger than normal. Oscillations were at 2.5 to 2.9 Hz. and not direction dependent.

SUBJENT: M.S.

Versions: M.S. was capable of good version response. She did show a tendency to predict the stimulus motion to both right and left gaze when the LE only, was stimulated and to the right only, during monocular RE and binocular stimulation. Oscillations were rare.

Symmetrical Vergence: Here M.S. showed very poor response to both SQ and SN, with many random blinks. She did not respond to all con/div stimuli and in cases where she did, there was an over-vergence tendency. Velocities were slow for both types of targets. Latencies were extremely large, especially during Sn response. There was an anticipatory trend during SQ divergence, (latency= +400 msecs.). The few oscillations demonstrated, were slow and large.

Asymmetric Vergence: Sq responses by the RE were small and slow. Div latency was twice that of conv (-425 and -263 msecs., respectively). RE SN response was of greater amplitude and was exactly in phase with the stimulus (phase lag= zero). M.S. was the only subject to match the target motion exactly. Response by the LE to both SQ and SN was larger and faster, particularly SQ conv. Latencies were very large, except for SN conv, where M.S. anticipated the stimulus by +167 msecs..

Accommodative Convergence: Response velocities were slightly slower than the control subject. Latencies were within normal limits at -50 to -300 msecs.. Oscillations were again at unexpectedly low frequencies, (≈1.5 Hz.). During all phases of asymmetric vergence and accommodative convergence, the LE moved much more smoothly and accurately than the RE.

SUBJECT: P.S.

Versions: P.S. demonstrated a consistent undershoot and immediate correction, upon movement to the right, to all SQ stimuli. This same characteristic was evidenced occassionally during SN stimulation also. Latencies and oscillations, when they did occur, were normal.

Symmetrical Vergence: Response amplitudes were close to expected, except for SQ div, which wes low. Velocities were slow ($\cong 5.0^{\circ}$/second). All latencies were very large, particularly during SN stimulation, where the lag approached -2.0 seconds, producing a 90 phase lag. Oscillations were at 3.0 to 6.1 Hz. and random.

Asymmetric Vergence: LE SQ amplitude was low. All response velocities compared well with the control subject, but as with the majority of our subjects, were slow relative to the literature norm of 40°/second. Monocular RE stimulation produced large latencies, inparticular during SQ tracking. The monocular LE condition showed more normal latency; in fact, during SN, the lag approached zero. Oscillations ranged from 2.6 to 6.3 Hz. and were not dirction dependent.

Accommodative Convergence: Conv velocities were slow, particularly during reciprocal accommodative convergence by the LE. All latencies were greater than -400 msecs. Oscillations were again at random and ranged from 2.4 to 4.2 Hz..

CONCLUSIONS

A number of general trends were expected and evident. Similar to others who have carried on related research, we find that strabismic eye movements tend to be characterized by; over-vergence (excessive movement), very slow velocities, large and variable latencies and general instability, (indicated by high variation of oscillation and blinking).

Specific to our study, binocular version response by squinters, shows no differences between latencies of rightward and leftward directions of gaze. However, individuals with an amblyopic or poorer eye, demonstrate a greater latency variance with that eye as opposed to their good eye. Monocularly, these same individuals exhibit more oscillations (instability) by the inferior eye.

Strabismics are capable of symmetrical conv and div SQ response, but when amplitudes are unequal, the conv movement is much larger than div and a blink is characteristic just prior to or during conv initiation. Vergence velocities are very slow and generally equal in both disjunctive movements. Again, when unequal, conv velocity is greater than that of the opposing motion. This same pattern holds for vergence latencies, where when unmatched, conv lags are longer. Oscillations are random and within normal frequency and amplitude limits or slightly slower than for normals. SN responses are similar to SQ response, with phase lags as great as 90 degrees.

Asymmetric stimulation shows no consistent response pattern to different targets by the same subject nor, to the same targets by different individuals. Generally, response is of poorer quality than that of symmetrical vergence and at a greater velocity.

Accommodative convergence stimulation produces a faster conv velocity than div in most subjects. In those with a poorer eye, both velocity and latency of response is much greater when this eye is stimulated. One unusual emerging trend is that, there may be a relationship between response latency and oscillation rate, i.e. slower latency correlates with faster oscillation.

A comparison of asymmetric vergence and accommodative convergence indicates that, when the same eye is moving in both situations, the quality of movement of accommodative convergence is much better than of asymmetric vergence, regardless of whether it is the good or poor eye in motion.

A final survey of this project has initiated some suggestions that may be helpful to future studies of disjunctive eye movements:

1. computor analysis of the eye-track recordings would greatly reduce the subjectivity or individual bias in data examination,

2. more extensive survey of non-disparate responses (versions), would make comparison of version and vergence movement a more usable correlation, and

3. more precise calculation of AC/A would produce more consistent reciprocal movement during accommodative convergence stimulation.

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